SEARCHES OF STELLAR MASS DARK MATTER FROM AN ANALYSIS OF VARIABILITIES OF HIGH RED-SHIFTED QSOs

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We consider a contribution of microlensing to the X-ray variability of high-redshifted QSOs. Such an effect could be caused by stellar mass objects (SMO) located in a bulge or/and in a halo of this quasar as well as at cosmological distances between an observer and a quasar. Cosmologically distributed gravitational microlenses could be localized in galaxies (or even in bulge or halo of gravitational macrolenses) or could be distributed in a uniform way. We have analyzed both cases of such distributions. As a result of our analysis, we obtained that the optical depth for microlensing caused by stellar mass objects is usually small for quasar bulge and quasar halo gravitational microlens distributions ($\tau \sim 10^{-4}$). On the other hand, the optical depth for gravitational microlensing caused by cosmologically distributed deflectors could be significant and could reach $10^{-2} - 0.1$ at $z \sim 2$. This means that cosmologically distributed deflectors may contribute significantlly to the X-ray variability of high-redshifted QSOs ($z > 2$). Considering that the upper limit of the optical depth ($\tau \sim 0.1$) corresponds to the case where dark matter forms cosmologically distributed deflectors, observations of the X-ray variations of unlensed QSOs can be used for the estimation of the dark matter fraction of microlenses.

The X-ray radiation of Active Galactic Nuclei (AGNs), in the continuum as well as in spectral lines, has rapid and irregular variability.[1] X-ray flux variability has long been known to be a common property of active galactic nuclei (AGNs), e.g. Ariel 5 and HEAO 1 first revealed long-term (days to years) variability in AGNs and by uninterrupted observations of EXOSAT rapid (thousands of seconds) variability was also established as common in these sources (see, for example reviews[2,3] and references therein). X-ray flux variations are observed on timescales

from ∼1000 s to years, and amplitude variations of up to an order of magnitude are observed in the ∼ 0.1 - 10 keV band. Recently, Manners at al.[1] analyzed the variability of a sample of 156 radio-quiet quasars taken from the ROSAT archive, considering the trends in variability of the amplitude with luminosity and with redshift. They found that there were evidences for a growth in AGN X-ray variability amplitude towards high redshift (z) in the sense that AGNs of the same X-ray luminosity were more variable at $z > 2$. They explained the σ *vs.* z trend assuming that the high-redshifted AGNs accreted at a larger fraction of the Eddington limit than the low-redshifted ones.

On the other hand, the contribution of microlensing to AGN variability was considered in many papers (see e.g. papers[4,5,6,7,8], and references therein). Moreover, recently X-ray microlensing of AGN has been considered.[9,10,11,12,13,14] Taking into account that the X-rays of AGNs are generated in the innermost and very compact region of an accretion disc, the X-ray radiation in the continuum as well as in a line can be strongly affected by microlensing.[11] Simulations of X-ray line profiles are presented in a number of papers, see, for example, papers[15,16,17,18,20] and references therein, in particular Zakharov et al.[21] showed that an information about magnetic field may be extracted from X-ray line shape analysis; Zakharov & Repin[22] discussed signatures of X-ray line shapes for highly inclined accretion disks.

Recent observations of three lens systems seem to support this idea.[23,13,14] Popović et al.[11] showed that objects in a foreground galaxy with very small masses can cause strong changes in the X-ray line profile. This fact may indicate that the observational probability of X-ray variation due to microlensing events is higher than in the UV and optical radiation of AGNs. It is connected with the fact that typical sizes of X-ray emission regions are much smaller than typical sizes of those producing optical and UV bands. Typical optical and UV emission region sizes could be comparable or even larger than Einstein radii of microlenses and therefore microlenses magnify only a small part of the region emitting in the optical or UV band (see e.g. papers,[10,24] for UV and optical spectral line region). This is reason that it could be a very tiny effect from an observer point of view.

The aim of the work is to discuss the contribution of microlensing to the relation σ *vs.* z for X-ray radiation considering the recent results given in papers.[1,11] The results of calculations and detailed discussions are presented in the paper.[25]

Just after the discovery of the first multiple-imaged quasar QSO 0957+561 A,B by Walsh et al.[26] the idea of microlensing by low mass stars in a heavy halo was suggested by Gott.[27] First evidence of quasar microlensing was found by Irwin et al.[28] Now there is a number of known gravitational lens systems[29,30] and some of them show evidence for microlensing.[6]

More than 10 years ago Hawkins[4] (see also paper[5]) put forward the idea that nearly all quasars are being microlensed. Hawkins[5] argued that the observational results favor the disc instability model for Seyfert galaxies, and the microlensing model for quasars. The starburst and disc instability models are ruled out for quasars, while the microlensing model is in good agreement with the observations.

As was mentioned earlier by Popović et al.[11] the probability of microlensing by stars or other compact objects in halos and bulges of quasars is very low (about $10^{-4} - 10^{-3}$). However, for cosmologically distributed microlenses it could reach $10^{-2} - 0.1$ at $z \sim 2$. The upper limit $\tau \sim 0.1$ corresponds to the case where compact dark matter forms cosmologically distributed microlenses. This indicates that such a phenomenon could be observed frequently, but only for distant sources ($z \sim 2$). Moreover, it is in good agreement with the trend in the variability amplitude with redshift,[1] where AGNs of the same X-ray luminosity are more variable at $z > 2$.

To investigate distortions of spectral line shapes due to microlensing the most real candidates are multiply imaged quasars. However, for these cases the simple point-like microlens model may not be very good approximation[6,7] and one should use a numerical approach, such as the MICROLENS ray tracing program, developed by J. Wambsganss or some analytical approach for

magnification near caustic curves like folds[31] or near singular caustic points like cusps[32,33,34,35] as was realized by Yonehara.[36]

If we believe in the observational arguments[5] that the variability of a significant fraction of distant quasars is caused by microlensing, the analysis of the properties of X-ray line shapes due to microlensing[11] is a powerful tool to confirm or rule out the Hawkins hypothesis.

As it was mentioned, the probability that the shape of the Fe $K\alpha$ line is distorted (or amplified) is highest in gravitationally lensed systems. Actually, this phenomena was discovered recently[23,14,13,37,38] who found evidence for such an effect for QSO H1413+117 (the Cloverleaf, $z = 2.56$), QSO 2237+0305 (the Einstein Cross, $z = 1.695$), MG J0414+0534 ($z = 2.64$) and possibly for BAL QSO 08279+5255 ($z = 3.91$). One could say that it is natural that the discovery of X-ray microlensing was made for this quasar, since the Einstein Cross QSO 2237+0305 is the most "popular" object to search for microlensing, because the first cosmological microlensing phenomenon was found in this object[28] and several groups have been monitoring the quasar QSO 2237+0305 to find evidence for microlensing. Microlensing has been suggested for the quasar MG J0414+0534[39] and for the quasar QSO H1413+117.[40] Therefore, in future may be a chance to find X-ray microlensing for other gravitationally lensed systems that have signatures of microlensing in the optical and radio bands. Moreover, considering the sizes of the sources of X-ray radiation, the variability in the X-ray range during microlensing event should be more prominent than in the optical and UV. Consequently, gravitational microlensing in the X-ray band is a powerful tool for dark matter investigations, as the upper limit of optical depth ($\tau \sim 0.1$) corresponds to the case where dark matter forms cosmologically distributed deflectors. The observed rate of microlensing can be used for estimates of the cosmological density of microlenses, but durations of microlensing events could be used to estimate microlens masses.[6,7]

From our calculations we can conclude:[25]

i) The optical depth in the bulge and halo of host galaxy is $\sim 10^{-4}$. This is in good agreement with previous estimates.[11] Microlensing by deflectors from the host galaxy halo and bulge makes a minor contribution to the X-ray variability of QSOs.

ii) The optical depth for cosmologically distributed deflectors could be $\sim 10^{-2} - 0.1$ at $z \sim 2$ and might contribute significantly to the X-ray variability of high-redshift QSOs. The value $\tau \sim 0.1$ corresponds to the case where compact dark matter forms cosmologically distributed microlenses.

iii) The optical depth for cosmologically distributed deflectors (τ_L^p) is higher for $z > 2$ and increases slowly beyond $z = 2$. This indicates that the contribution of microlensing on the X-ray variability of QSOs with redshift $z > 2$ may be significant, and also that this contribution could be nearly constant for high-redshift QSOs. This is in good agreement with the fact that AGNs of the same X-ray luminosity are more variable at $z > 2$.[1]

iv) Observations of X-ray variations of unlensed QSOs can be used for estimations of matter fraction of microlenses. The rate of microlensing can be used for estimates of the cosmological density of microlenses, and consequently the fraction of dark matter microlenses, but the durations of microlensing events could be used for gravitational microlens mass estimations.

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